Section 27
Heterojunction Bipolar Transistor

27.7 Double heterojunction HBTs

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PURDUE UNIVERSITY

School of Electrical and Computer Engineering

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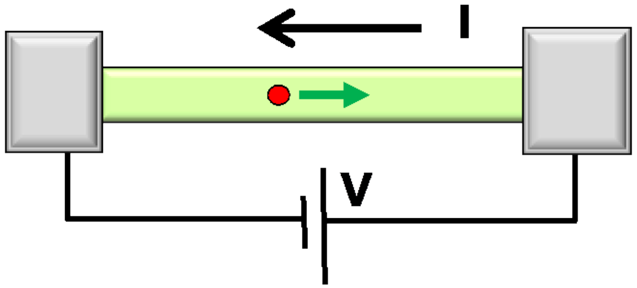

$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area

$$\beta_{poly,ballistic} \rightarrow \frac{n_{i,B}^2}{n_{i,E}^2} \times \frac{N_E}{N_B} \times \frac{\upsilon_{th}}{\upsilon_s}$$

$$\frac{n_{i,B}^2}{n_{i,E}^2} = \frac{N_{C,B} N_{V,B} e^{-E_{g,B}\beta}}{N_{C,E} N_{V,E} e^{-E_{g,E}\beta}} \approx e^{(E_{g,E} - E_{g,B})\beta}$$

$$J_n = q\left(\frac{n_{iB}^2}{N_{AB}}\right)\frac{D_n}{W_B} e^{qV_{BE}/k_BT}$$

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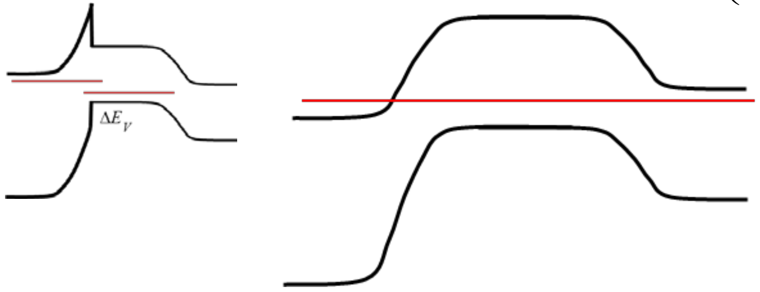
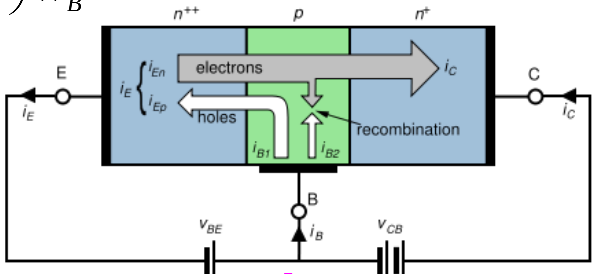
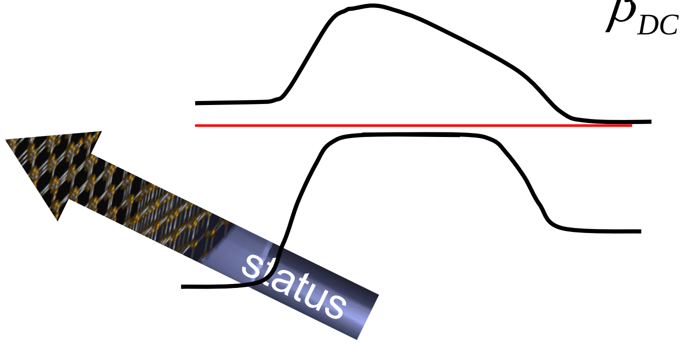
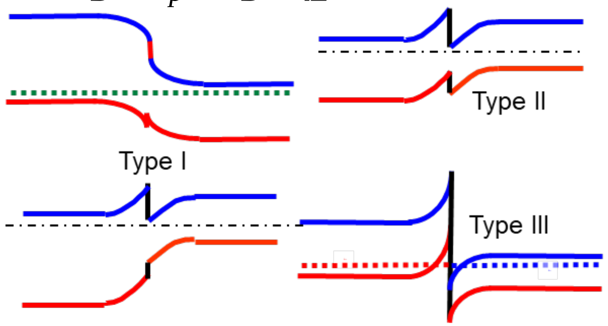




$$\beta_{DC} = \frac{N_E}{N_B}\frac{D_n}{D_p}\frac{W_E}{W_B}\frac{\overline{n}_{iB}^2}{n_{iE}^2}$$





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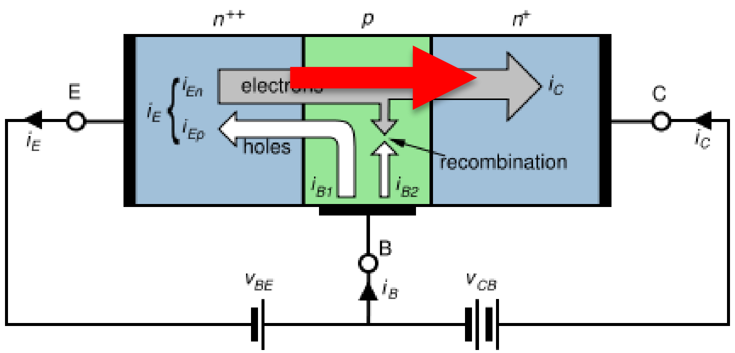
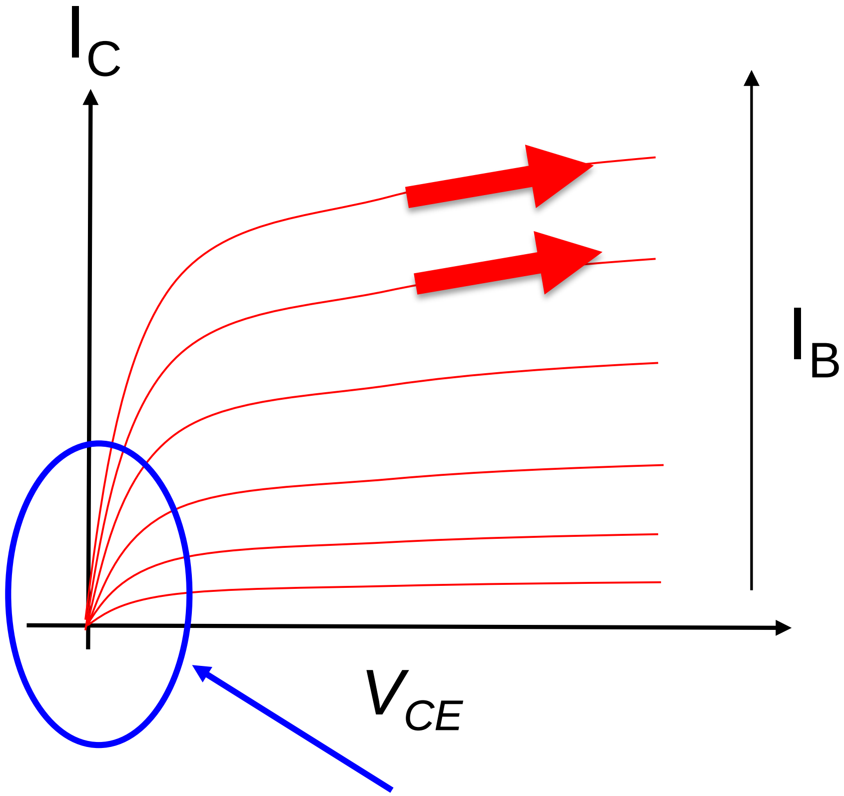
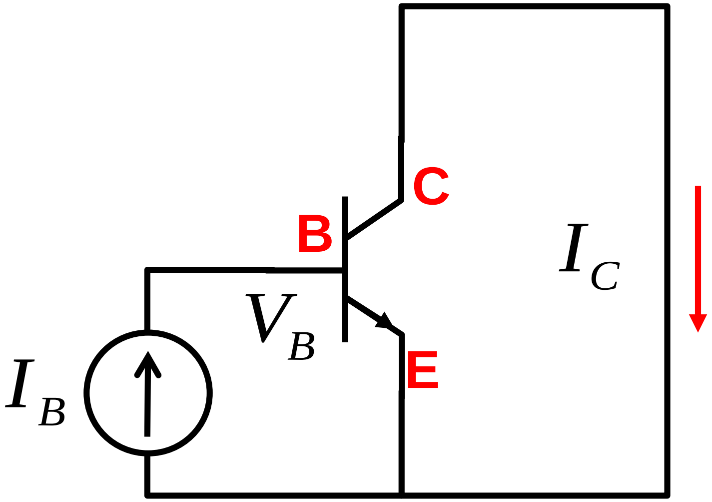
Offset Voltage - What happens when $V_{CE}=0$

So far we always considered a reverse bias on BC junction

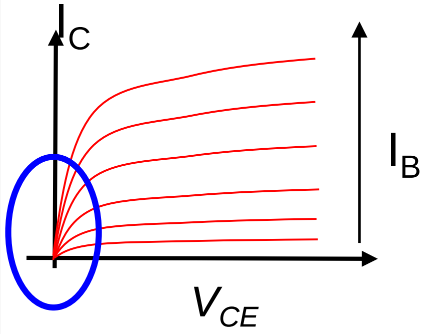


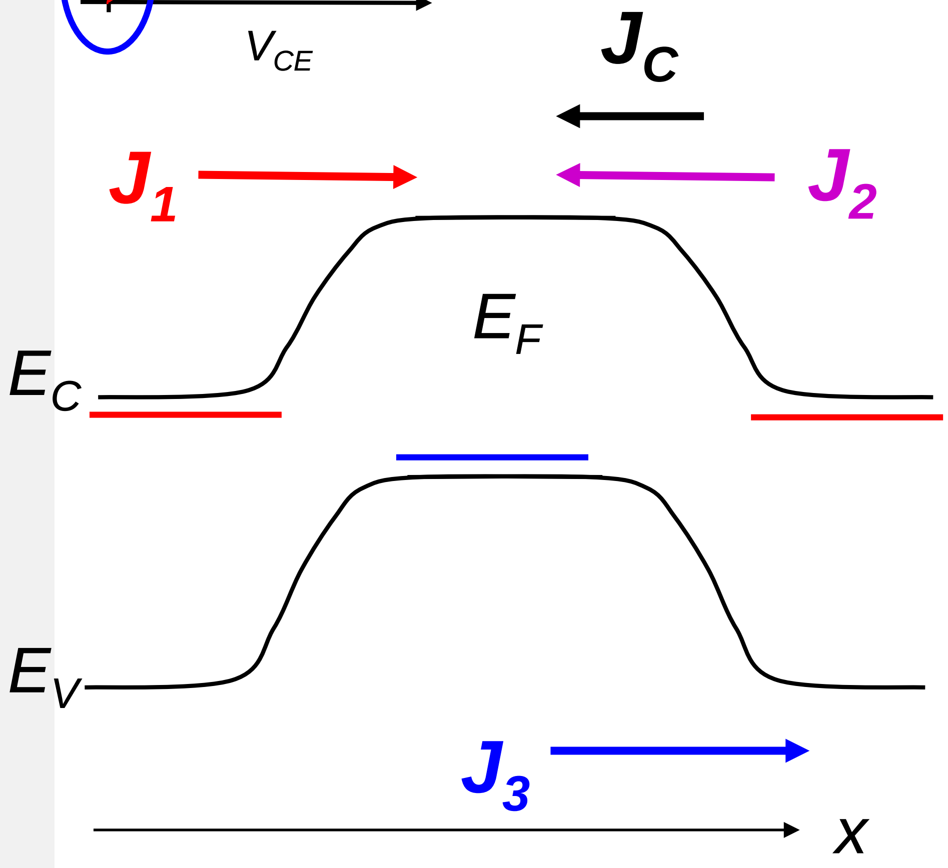


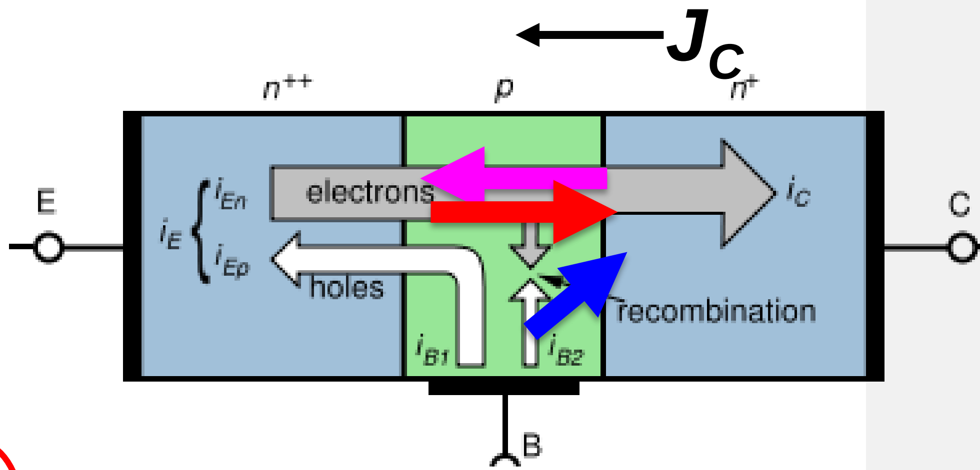


does $I_C = 0$ at $V_{CE} = 0$?

Offset Voltage







$$J_1 = q\left(\frac{n_{iB}^2}{N_{AB}}\right)\frac{D_n}{W_B}e^{q(V_B - V_E)/k_BT}$$ electrons

$$J_2 = q\left(\frac{n_{iB}^2}{N_{AB}}\right)\frac{D_n}{W_B}e^{q(V_B - V_C)/k_BT}$$ electrons

$$J_3 = q\left(\frac{n_{iC}^2}{N_{DC}}\right)\frac{D_p}{W_C}e^{q(V_B - V_C)/k_BT}$$ holes

$$J_C = J_1 - J_2 - J_3$$

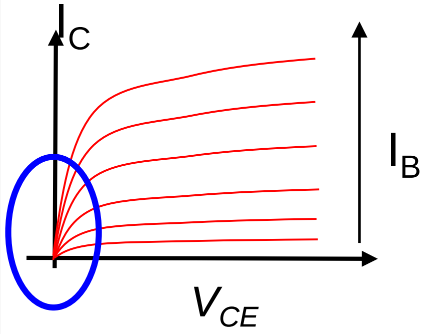
J_1 and J_2 are balanced for identical voltages

J_3 causes an additional component

J_3 and J_2 need to balance J_1 at $V_E = 0$

set $J_C = 0$, assume $V_E = 0$, solve for $V_C = V_{OS}$

Offset Voltage



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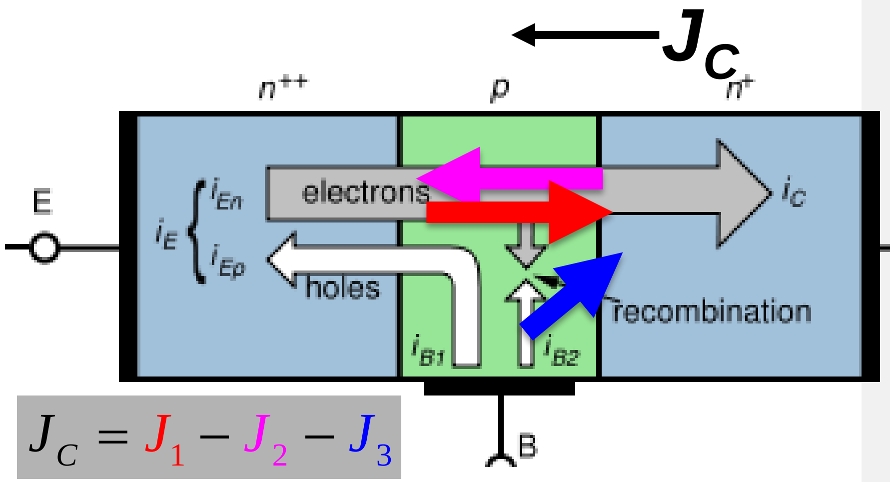
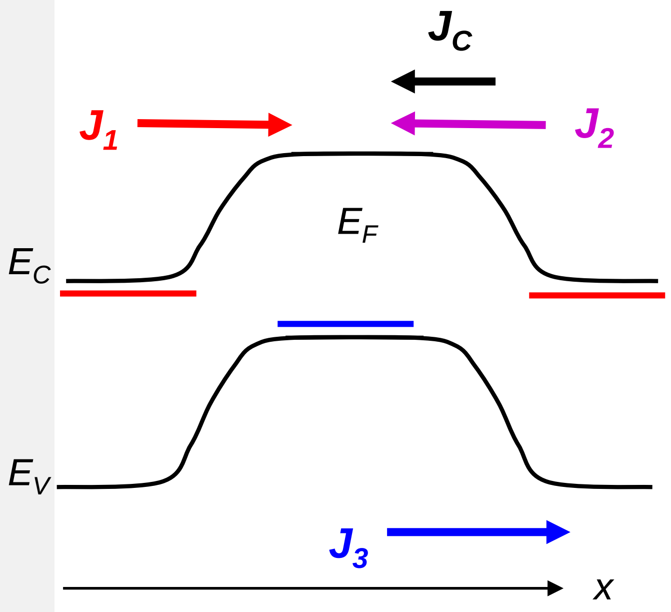


$$J_C = J_1 - J_2 - J_3$$

set $J_C = 0$, assume $V_E = 0$, solve for $V_C=V_{OS}$



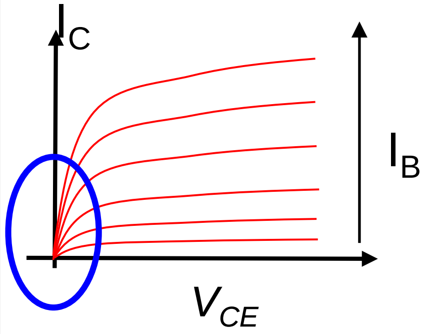
J_3 and J_2 need to balance J_1 at $V_E = 0$

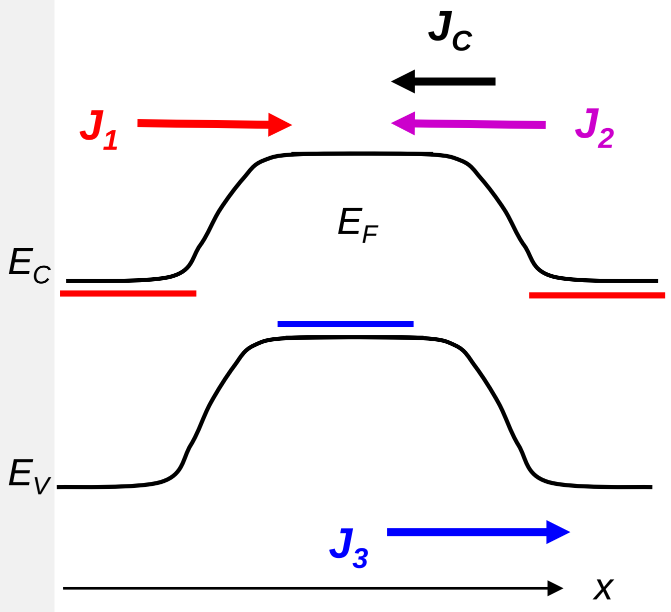
$$\gamma_R = \frac{J_2}{J_3} = \frac{\left(n_{iB}^2/N_{AB}\right)\left(D_n/W_B\right)}{\left(n_{iC}^2/N_{DC}\right)\left(D_p/W_C\right)}$$

(Reverse Emitter injection efficiency)

$$V_{OS} = \frac{k_BT}{q}\ln\left(1+1/\gamma_R\right)$$

Offset Voltage





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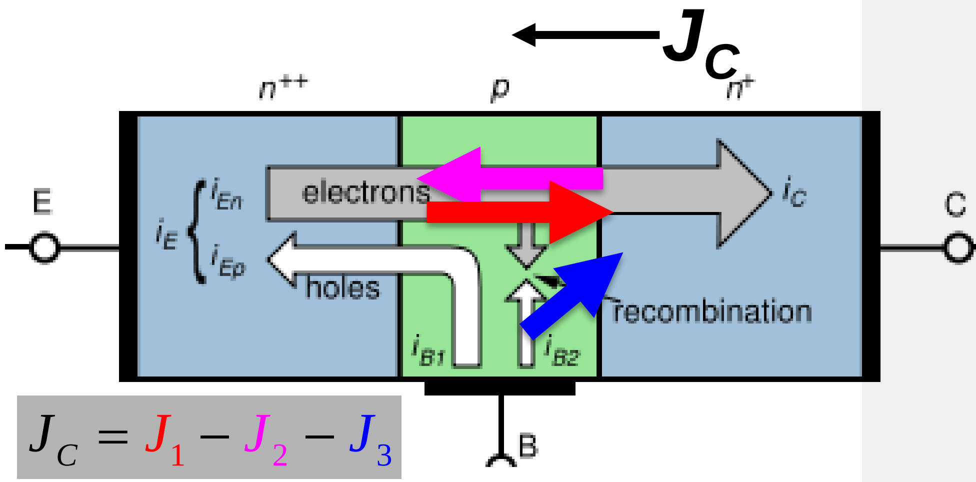
set J_C = 0, assume V_E = 0, solve for V_C=V_{OS}



$$J_C = J_1 - J_2 - J_3$$

J_3 and **J_2** need to balance **J_1** at V_E = 0

$$\gamma_R = \frac{J_2}{J_3} = \frac{\left(n_{iB}^2/N_{AB}\right)\left(D_n/W_B\right)}{\left(n_{iC}^2/N_{DC}\right)\left(D_p/W_C\right)}$$

(Reverse Emitter injection efficiency)

$$V_{OS} = \frac{k_BT}{q}\ln\left(1+1/\gamma_R\right)$$

ideally **J_3** as small as possible

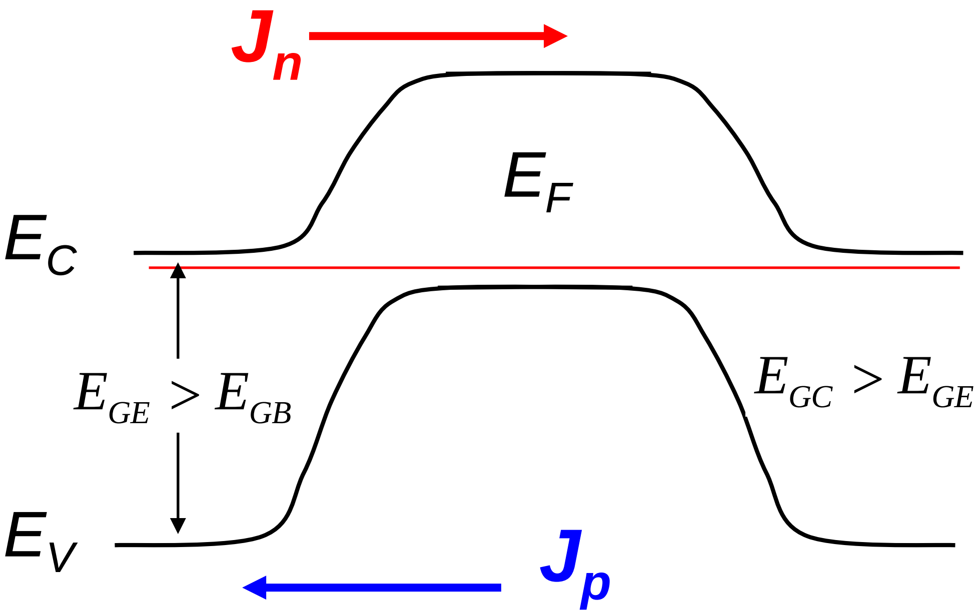
$$\gamma_R \Rightarrow very\ large$$

$$V_{OS} \Rightarrow very\ small$$

=> Increase gap in Collector

Same idea as β_{DC} increase!

Double HBJT - large collector bandgap



$\gamma_R \Rightarrow very\ large$

Same idea as β_{DC} increase!

- Reduce $V_{OS} = \frac{k_B T}{q} \ln\left(1 + 1/\gamma_R\right)$
- High voltage operations for high power devices
- Higher collector bandgap:
  - Reduced avalanche (3/2 E_G)
  - Increased Kirk current (keep control of collector junction)
- Symmetric operation can simplify circuits

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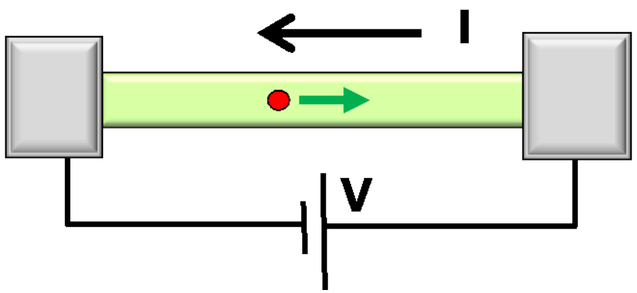

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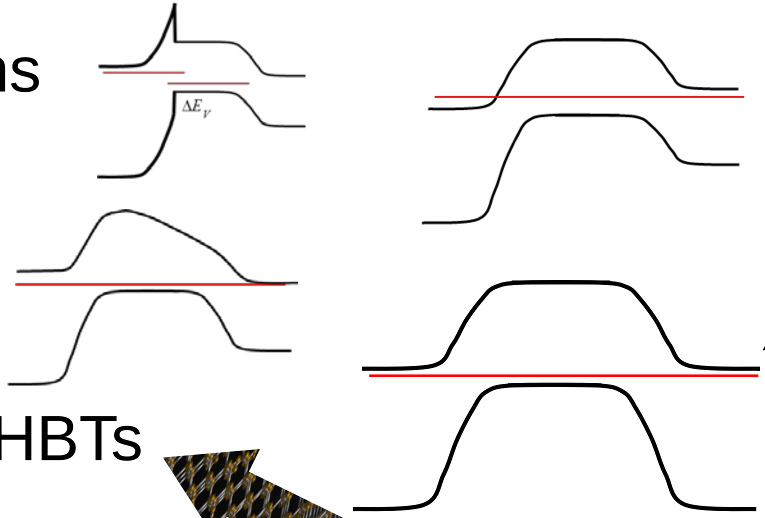

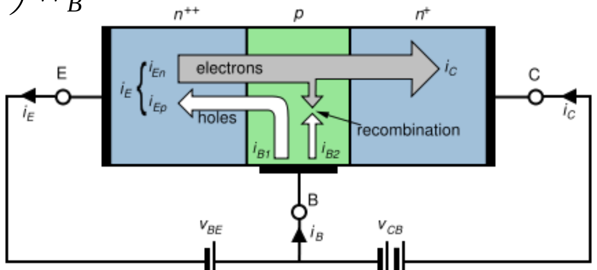

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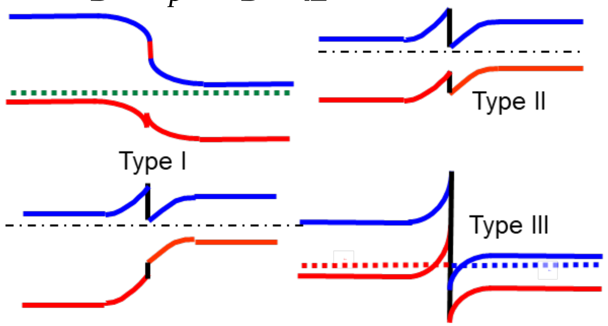

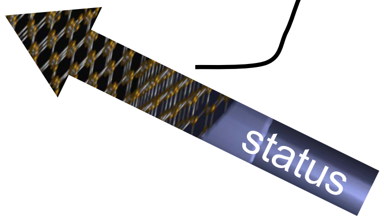

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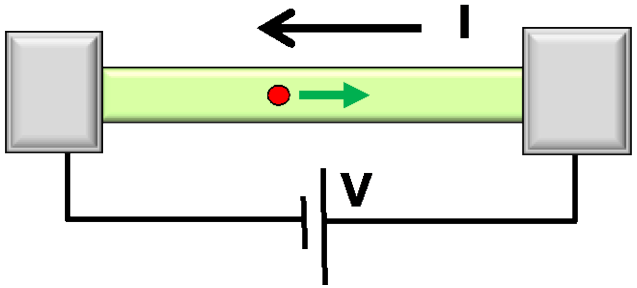

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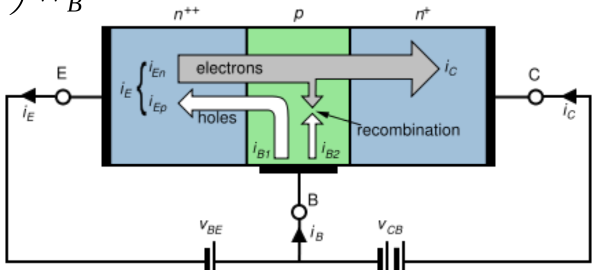

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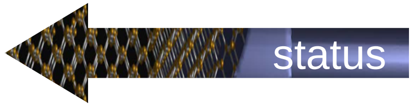

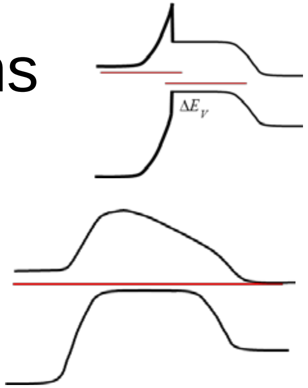

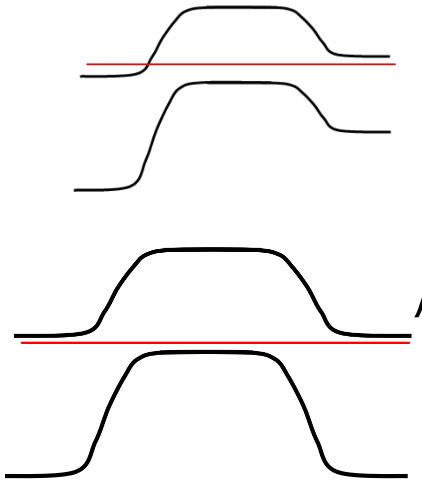

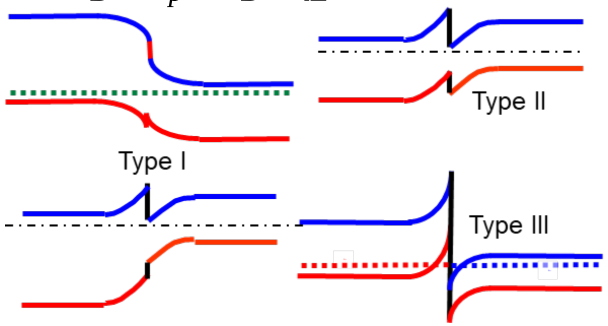

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